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EYE METRICS: AN ALTERNATIVE VIGILANCE DETECTOR FOR MILITARY CYBER OPERATORS

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NOTICE AND SIGNATURE PAGE

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14. ABSTRACT
The purpose of this study was to investigate the use of an eye-tracker to detect changes in vigilance performance during a simulated cyber operator task. The significant change of oculometric measurements indicates that oculometrics could be used to detect changes in sustained attention for cyber operators. Future research is needed to assess the real-time effects of these oculometrics on vigilance performance, especially in a real-world setting.

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1.0 SUMMARY

Military cyber operators are required to use sustained attention or vigilance for long time periods. During this time they encounter lapses in attention due to the sometimes monotonous nature of their tasks. Mistakes during these tasks can have serious consequences to our national security. The purpose of this study was to investigate the use of an eye-tracker to detect changes in vigilance performance during a simulated cyber operator task. Twenty participants performed four sessions of a 40-minute vigilance task while wearing an eye-tracker. Blink frequency, blink duration, PERCLOS, pupil diameter, pupil eccentricity, pupil velocity, and signal detection all had a significant change over time ($p<.05$) during the vigilance task. The significant change of oculometric measurements indicates that oculometrics could be used to detect changes in sustained attention for cyber operators. Future research is needed to assess the real-time effects of these oculometrics on vigilance performance, especially in a real-world setting.

2.0 INTRODUCTION

Sustained attention and vigilance are important issues in today's military cyber operator environment. Cyber operators are required to monitor several screens of various networks' traffic information to look for specific keywords, internet protocol (IP) addresses, etc. When identified, they must forward the information on to intelligence services for further analysis (Lin, 2010). Cyber operators experience a high degree of routine with few incidents while monitoring significantly large amounts of data (Donald, 2008). This type of work requires divided attention, selective attention, effective scan patterns, sustained attention, and a large working memory capacity (Donald, 2008). Lapses in attention can cause incidents to go unnoticed. It is well established in the cognitive performance literature that operator performance on tasks requiring sustained attention or vigilance degrades with time; this is known as the "vigilance decrement" (Hitchcock, Warm, Matthews, Dember, Shear, Tripp, Mayleben, & Parasuraman, 2003). During the vigilance decrement, critical errors are made that can have severe or even deadly consequences (Hawley, 2006). This leads to an increasing need to employ an unobtrusive way to monitor operator vigilance in this setting.

These sometimes devastating lapses in attention are possibly due to the monotonous and sometimes boring nature of these careers (Frankmann & Adams, 1962; Nachreiner & Hanecke, 1992). Various eye metrics have long been associated with arousal levels. Several researchers have found that eye tracking technologies can detect fatigue, boredom, and lapses in attention (Dinges, Mallis, Maislin, & Powell, 1998; Russo et al., 1999). Specifically, reduced alertness has been found when eye blinks are longer in duration (Stern, 1999). In fact, the use of eye tracking technology is employed regularly in the trucking industry to monitor driver arousal because performance becomes less consistent and vigilance deteriorates as a person's sleepiness increases (Dinges, 1990). Another metric that provides alertness information, especially in the trucking industry, is PERCLOS (percentage of eye closure); it is the most widely used measure of real-time alertness in this industry (Dinges & Grace, 1998; Mallis et al., 1999). However, these findings are the result of studies on sleep-deprived participants who are not tested on vigilance tasks.

While research on eye tracking in regards to vigilance is not as extensive as in the fatigue literature, studies using laboratory vigilance tasks have found some promising results using oculometrics to detect attentional levels. Several studies have indicated that eye gaze is related to attention (Blake & Sekuler, 2006; Kramer & McCarley, 2003; Palmer, 1999); therefore, eye movements may be closely related to our attentional levels. For example, some have found that well-rested participants who are placed in a well-lit room but asked to do a boring repetitive task, similar to our task, will mimic the pupil dilations of a sleep deprived individual placed in a dark room (Nishiyama, Tanida, Kusumi, & Hirata, 2007; Warga, Ludtke, Wilhelm, &Wilhelm, 2009). In both instances the pupils dilate initially before becoming miotic

(Lowenstein, Feinberg, & Lowenfeld, 1963; Ludtke et al., 1998). Beatty (1982) tested this finding with an auditory vigilance task and found that pupil diameter decreased as a function of time-on-task. In a previous study we found that the oculometrics of blink duration, blink frequency, PERCLOS, pupil diameter, pupil velocity, and pupil eccentricity could be indicators of vigilance task performance (McIntire, McKinley, Goodyear, Merrit, Griffin, McIntire, & Bridges, 2011). These various findings coupled with the extensive amount of research with sleep deprived individuals lead us to believe that oculometrics may provide a reliable method for assessing operator vigilance. In this study we will attempt to replicate our previous findings using a more real-world relevant task that requires not only sustained attention but working memory and divided attention, much like that would be found in a cyber operators environment, to determine if the similar results can still be found operationally.

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

3.1 Participants

A total of 20 participants (15 male, 5 female) completed this study. Male and female civilian and active duty participants were between the ages of 21-41 years (M = 26.1). Participants were compensated $10/hr for their time. Participants were not included in this study if they required eyeglasses for vision correction because the eye-tracker was mounted on eyeglass frames. The use of contact lenses was allowed.

3.2 Equipment

3.2.1 Eye-Tracker.

Each participant was required to wear the Eye-Com (Reno, NV) alertness monitoring device (see Figure 1) during the vigilance task which was repeated across four test sessions, each on different days. The device consisted of two infrared (IR)-sensitive cameras and a linear array of IR-illuminating light emitting diodes (LEDs) mounted on a set of eyeglass frames. The wavelength of the LEDs was 840 nm. The cameras were angled upward toward the eyes and extracted real-time pupil diameter, eye-lid movement, and eye-ball movement. The software recorded a variety of measurements including eye-blink duration, eye-blink frequency, eye-blink velocity, percentage of time the eyes are closed (PERCLOS), and pupil size. The sampling frequency of this device's data recording was 30 frames per second. The tracker monitored blink duration and frequency by tracking the occlusion of the pupil. When 85% of the pupil was occluded by the eyelid the eyes were considered closed for that particular frame. To be considered a "blink" for our analysis the pupil had to be occluded for at least 3 frames because median blink rates for alert individuals usually fall between 130-170 milliseconds (Schleicher, Galley, Briest, & Galley, 2008). If there were less than 3 frames in a row that indicated the eyes were closed, it was just considered a bad data point where the tracker lost the pupil momentarily.

Figure 1. Eye-Com Eye Tracker

PERCLOS is a metric that is calculated by the eye-tracker by measuring the proportion of the pupil that is occluded by the upper eyelid. Therefore, PERCLOS is the proportional amount of time when at least 80% of the pupil is occluded by the eyelid in a 1 minute time frame. Pupil velocity is calculated by tracking how far the pupil moved in a single frame by the location of the pupil on the previous frame. Pupil eccentricity is the extent to which the shape of the pupil deviated from being circular. The shape changes to more elliptical due to occlusion from the eyelid. Therefore, this metric is more a function of the nuance in the pupil tracker than a physiological change in shape. However, it can still provide valuable information about attention if it also reflects information about the eyelid and blinking.

3.2.2 Vigilance Task.

Participants performed a 40-minute vigilance task that was designed to simulate a cyber defense operator's task. The Cyber Defense Task (CDT) was developed by University of Dayton Research Institute (UDRI) to simulate tasks representative of those found in Cyber Defense Operations. The task is comprised of two components that run simultaneously. The first is a textual component where the participant was asked to monitor and respond to the presence of a suspicious internet protocol (IP) address and port combination entering the network. The second component is a graphics task where the participant was asked to monitor and respond to a dangerous increase in overall traffic within the network (Figure 2). The participant was asked to memorize three specific IP addresses before beginning the task. These IP addresses were suspicious and once they were recognized, the participant was required to press a key on the keyboard to provide an alert to their presence. The other portion of the task showed a simulated 2-D graph of overall IP traffic on the network. Here, the participant had to press a key when the IP traffic exceeded a predefined limit denoted by a horizontal red line. Both the textual and graphical task had a critical signal event rate of 5%. At the top of the display there were also three distracter graphs. Participants were not required to take any action on these static images. Performance efficiency was assessed in terms of the percentage of correct signals detected (percent hits). This variable was calculated every 10 minutes over the continuous 40 minute period. Measuring over 10-minute epochs was conducted because the critical signals were designed to appear at random from one trial to the next, but at a specific event rate within 10 minute segments of trials (5%). A new stimulus was displayed every 2000 msec for the graphical portion of the task and every 4000 msec for the textual portion. These rates were chosen based on piloting study results.

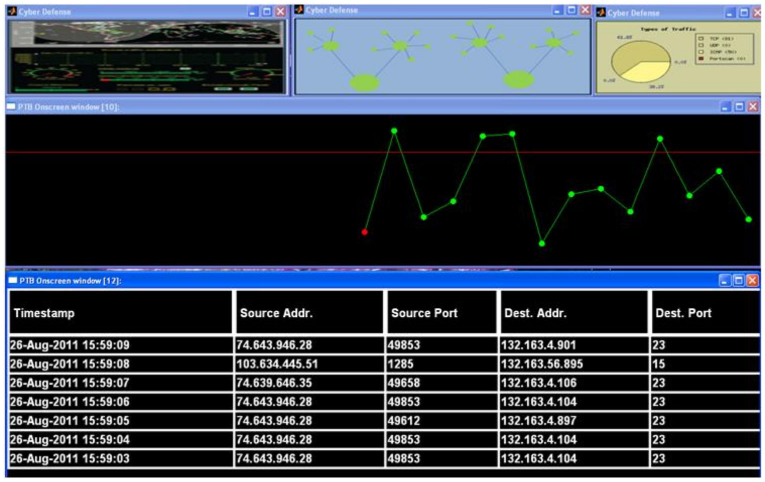

Figure 2. Cyber Defense Task

3.2.3 Vigilance Tasks are very Sensitive.

Participants were run in a room isolated from any noise and participants were required to wear ear plugs. Light levels were maintained to be consistent throughout the experiment and glare from the lights onto the task screen was minimized as much as possible. Participants were kept away from any possible distractions including being able to see the experimenters. In this study, a half wall was used to isolate the participant from the experimenter. The experimenters were able to see the participant and what they were doing but the participant was not able to see the experimenters.

3.3 Procedures

No study specific procedures were performed without a written and signed informed consent document. After the participant was consented and registered into the study, training on the vigilance task began. Participants received a verbal briefing and PowerPoint presentation that described the vigilance task followed by two 5-minute practice sessions. Also during this time the participant was to complete a personality and brief demographic questionnaire. Participants then donned the eye-tracker and completed the 40-minute vigilance task. Afterwards, the participants were finished for that day and returned to their normal duties. Each participant completed four data collection sessions. Each data session occurred on a separate day. During each data collection session, they repeated the procedures of the initial session except for the personality inventory and training sessions.

3.4 Data Analysis

Upon completion of testing, oculometric data and vigilance task metrics were averaged in 10-min increments (10, 20, 30, 40 min) and used as dependent variables in univariate repeated-measures analyses of variance (ANOVAs). The performance data from the dual task was averaged together to give a total score for each time epoch. Factors were Day (1 – 4) and Time (10, 20, 30, 40 min). Statistical significance tests were based on an alpha level of .05. Some participants had a day of performance data that was not usable due to incorrect data recording. During post processing it was discovered that the CDT had one IP address that the data did not record properly causing the need to remove that day of performance from the data analysis if the participant's data had that IP address. As a result, a participant's data was not included in analysis unless there were at least three sessions (days) of usable data. Proc Mixed in SAS was used to perform the repeated-measures ANOVAs. This procedure uses maximum likelihood to estimate covariances within a subject and then uses these covariance estimates to estimate coefficients for fixed effects. Satterthwaite-type degrees of freedom were used for all F-tests (SAS

Version 9.2). Least squares means (LSMeans) are means adjusted for missing data and were used since there were some instances where the eye-tracker lost the pupil during data collection.

Next, each participant's days were categorized as either a Decrement or No Decrement day depending on the percent hits performance. If the linear best-fit slope on a participant's percent hits across the four temporal epochs on a given day was negative, the data day was considered as a Decrement. Positive slopes or zero + 0.1 slopes were considered a No Decrement day. For each participant, variables were averaged across days at each time point, separately for Decrement and No Decrement days. Pearson partial correlations controlling for subject (same as ANOCOV with subject as a factor) were performed separately for Decrement and No Decrement days to relate percent hits performance to the six oculometrics.

4.0 RESULTS AND DISCUSSION

4.1 Results

Results are presented in two different sections. First, we present the results for the Day and Time ANOVAs. Second, we present the correlations of the 12 variables in relation to percent hits. Both analyses included all 20 participants.

4.1.1 Analysis for Day and Time.

The repeated measures ANOVA results with factors Day (1, 2, 3, 4) and Time (10, 20, 30, 40 min) are displayed in Table 1 below. Significant F-tests have the p-value cell grayed. ANOVAs were used to compare days and times for each of the variables.

Table 1. ANOVA Results for Day and Time

	Day				Time				Day*Time			
Dependent Variable	**DF**	**DFe**	**F**	**p**	**DF**	**DFe**	**F**	**p**	**DF**	**DFe**	**F**	**p**
Percent Hits (graph)	3	55.0	6.58	0.0007	3	219.0	2.51	0.0593	9	219.0	0.84	0.5793
Percent Hits (text)	3	56.2	2.09	0.1122	3	55.3	0.64	0.5933	9	166.2	0.64	0.7651
Left Blink Frequency (blpm)	3	55.9	0.42	0.7390	3	57.4	9.31	0.0001	9	169.3	1.87	0.0596
Right Blink Frequency (blpm)	3	56.1	0.93	0.4321	3	57.4	6.34	0.0009	9	168.9	3.33	0.0009
Left Blink Duration (ms)	3	56.0	2.09	0.1112	3	57.1	29.59	0.0001	9	169.0	1.06	0.3944
Right Blink Duration (ms)	3	56.1	1.81	0.1565	3	57.5	25.88	0.0001	9	169.3	2.33	0.0168
Left PERCLOS	3	56.1	0.33	0.8005	3	57.4	18.95	0.0001	9	169.7	1.64	0.1070
Right PERCLOS	3	56.1	0.62	0.6030	3	57.5	13.70	0.0001	9	169.3	1.80	0.0706
Left Pupil Diameter (mm)	3	56.0	4.60	0.0060	3	57.6	27.78	0.0001	9	169.4	1.77	0.0780
Right Pupil Diameter (mm)	3	56.1	1.08	0.3666	3	56.1	47.84	0.0001	9	167.9	2.64	0.0070
Left Pupil Eccentricity	3	56.0	0.64	0.5942	3	56.9	13.95	0.0001	9	168.6	0.74	0.6755
Right Pupil Eccentricity	3	56.1	1.88	0.1432	3	56.8	10.76	0.0001	9	168.4	0.67	0.7364
Left Pupil Velocity (deg/s)	3	56.0	2.73	0.0527	3	57.5	44.80	0.0001	9	169.7	0.78	0.6307
Right Pupil Velocity (deg/s)	3	56.0	2.16	0.1029	3	57.3	45.30	0.0001	9	169.3	0.84	0.5843

The Day of data collection had a significant effect on Percent Hits for the graphical portion of the task as well as Left Pupil Diameter (Table 1 & Figure 4). Percent Hits increased as the participation day progressed (Figure 3). On Day 1 average diameter was 8.35 mm (SEM = 0.12) and Day 4 the average diameter for the left eye was 8.12 mm (SEM = 0.12).

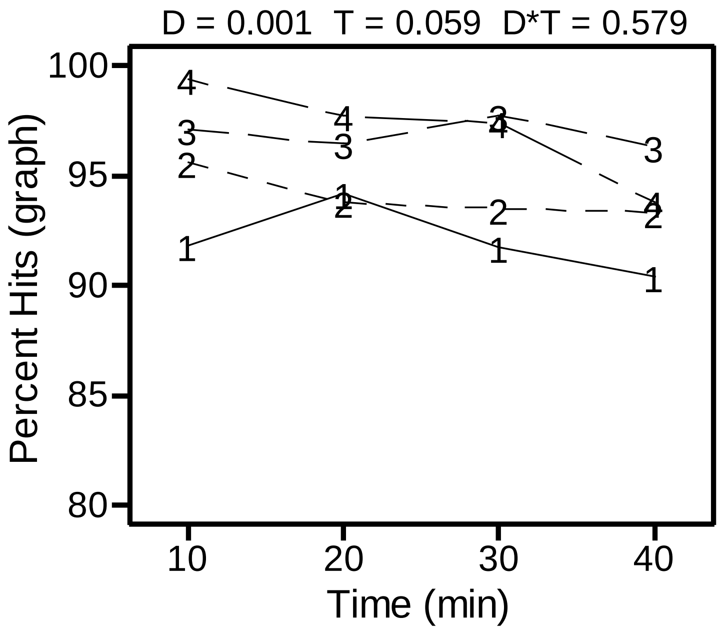

Figure 3. Percent Hits Across Time, by Day

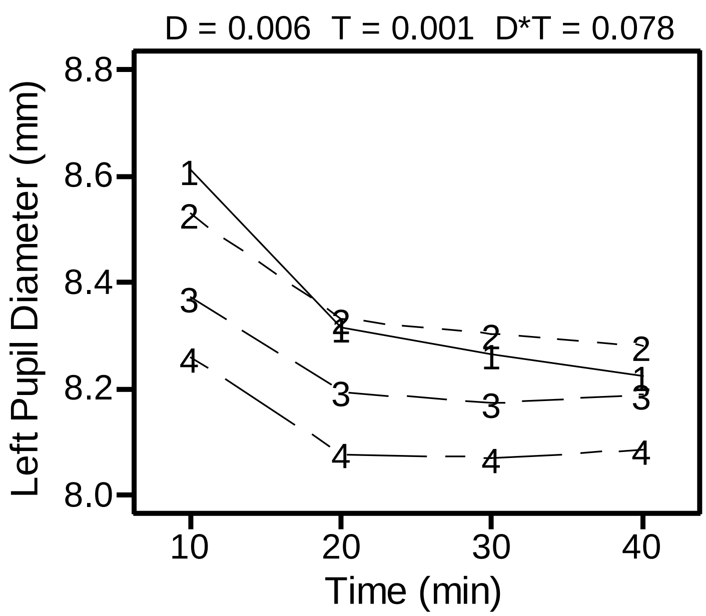

Figure 4. Left Eye Pupil Diameter Across Time, by Day

Time on task had a significant effect on Left and Right Blink Frequency, Left and Right Blink Duration, Left and Right PERCLOS, Left and Right Pupil Diameter, Left and Right Pupil Eccentricity, and Left and Right Pupil Velocity. As the Time on task progressed, Left and Right Blink Frequency increased (Figure 5). The LSMean across the four days for the first 10 minutes of the task was 17.1 blinks per minute (SEM = 2.3) in the left eye and 21.3 (SEM = 2.3) blinks per minute for the final 10 minutes of the task. The right eye had similar results with 16.0 blinks per minute (SEM = 2.2) during the first 10 minutes of the task and 20.0 blinks per minute (SEM = 2.2) for the final 10 minutes of the task. This equates to a 25% increase in blinking frequency for the left and right eye.

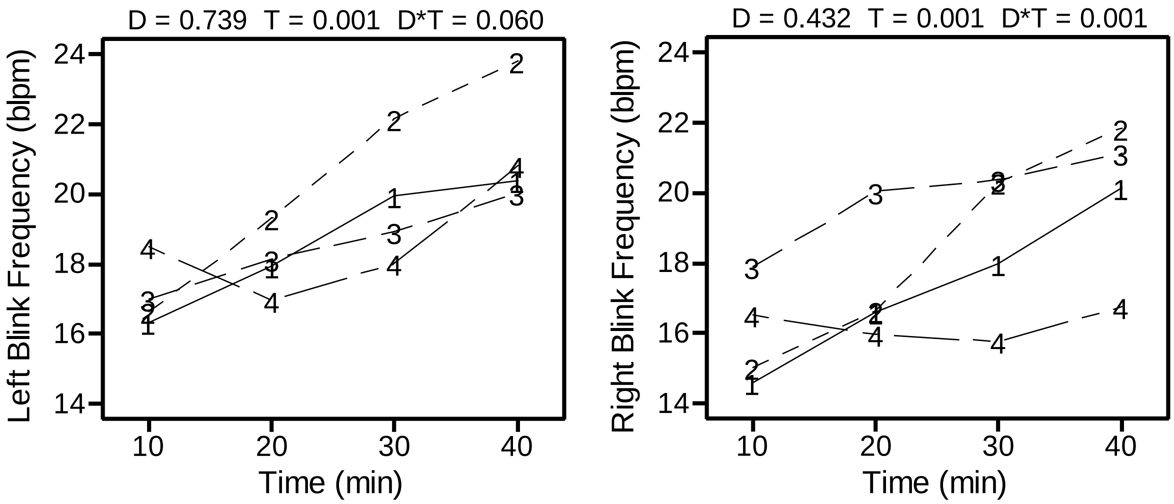

Figure 5. Left and Right Eye Blink Frequency Across Time, by Day

As Time on task increased from the first 10 minutes of the task to the last 10 minutes of the task, Left and Right Blink Durations became longer (Figure 6). The LSMean for the first 10 minutes of the task across the four days was 196.8 ms (SEM = 7.8) in the left eye and 191.7 ms (SEM = 5.1) in the right eye. Whereas, the LSMean for the final 10 minutes of the task was 218.2 ms (SEM = 7.8) in the left eye and 210.4 ms (SEM = 5.1) in the right eye. This equates to 11% longer blink durations in the left eye and 10% longer blink durations in the right eye.

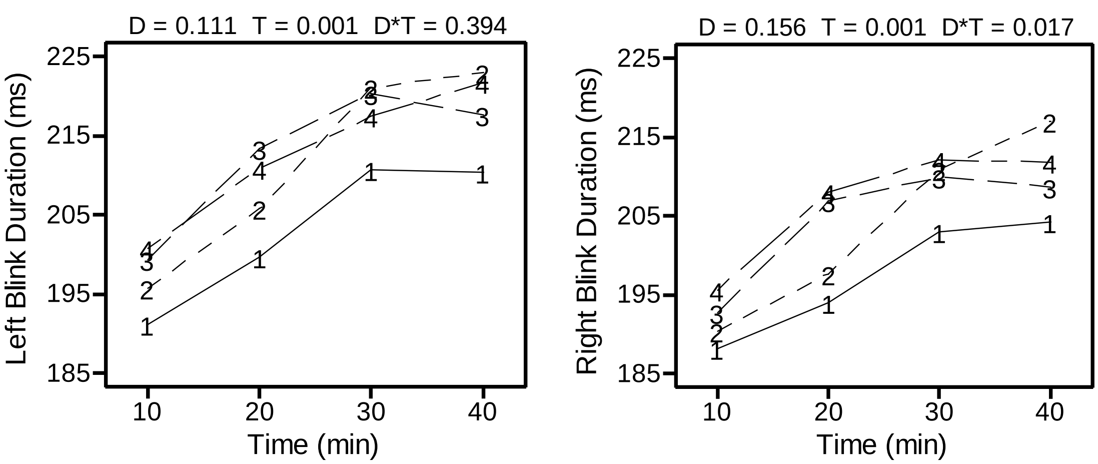

Figure 6. Left and Right Eye Blink Duration Across Time, by Day

Left and Right PERCLOS increased as Time on the task increased (Figure 7). During the first 10 minutes of the task PERCLOS in the left eye had an LSMean across all four days of 4.19% (SEM = 1.04) and 3.76% (SEM = 0.89) in the right eye. During the last 10 minutes of the task the LSMean for the left eye was 6.73% (SEM = 1.04) and 5.81% (SEM = 0.89) in the right eye.

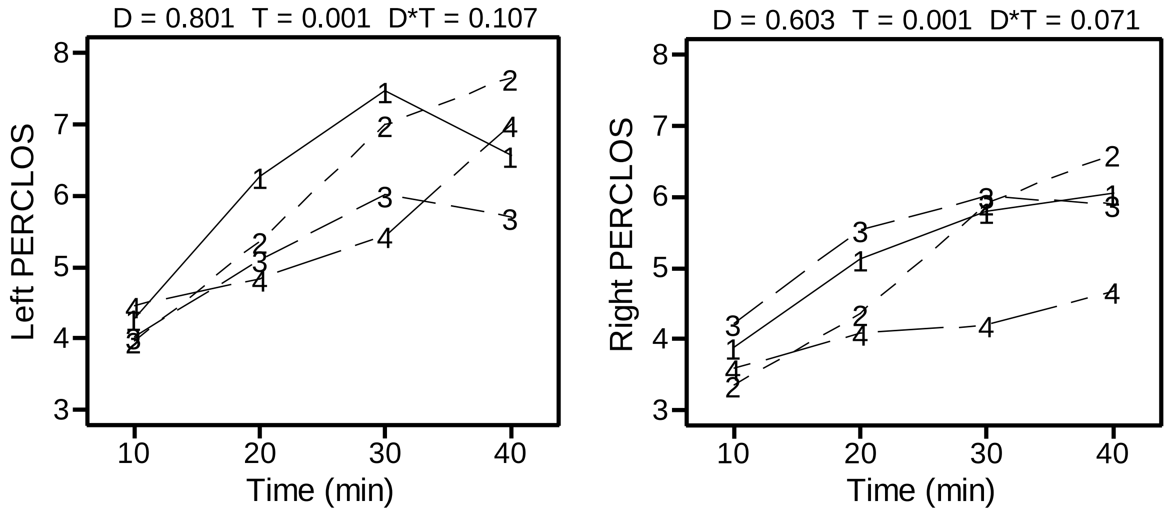

Figure 7. Left and Right Eye PERCLOS Across Time, by Day

Time on task also had a significant effect on Left and Right Pupil Diameter. As Time on the task increased, Pupil Diameter decreased (Figure 8). During the first 10 minutes of the task, the LSMean for Left Pupil Diameter across the four days was 8.44 mm (SEM = 0.12) and Right Pupil Diameter was 8.49 mm (SEM = 0.13). For the last 10 minutes of the task the LSMean for Left Pupil Diameter was 8.20 mm (SEM = 0.13) and Right Pupil Diameter was 8.22 mm (SEM = 0.13). This equates to a 3% decrease in pupil diameter for both eyes.

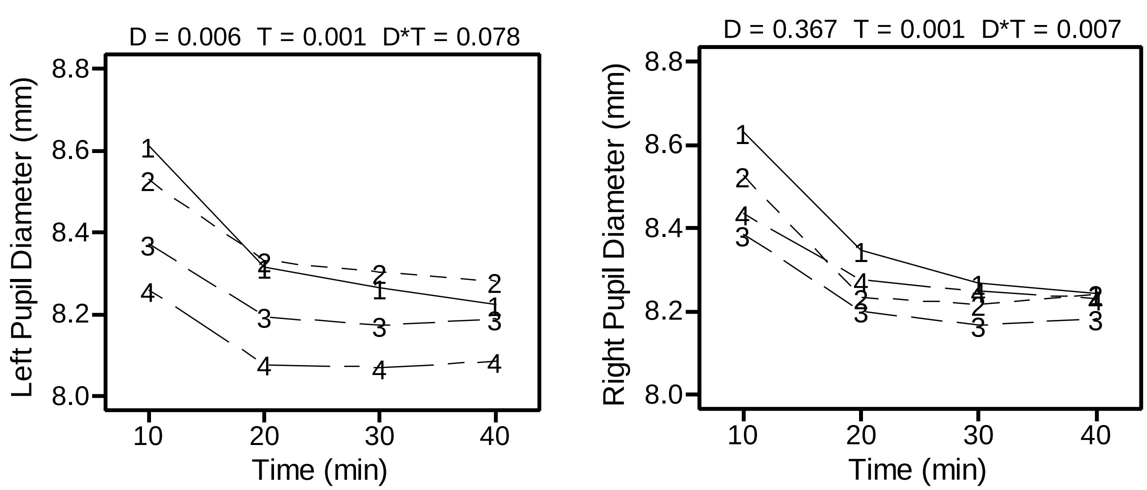

Figure 8. Left and Right Eye Pupil Diameter Across Time, by Day

Left and Right Pupil Eccentricity increased as a function of Time on task increasing (Figure 9). During the first 10 minutes of the task the LSMean across the four days in the Left eye was 0.524 (SEM = 0.014) and the Right eye was 0.484 (SEM = 0.013). During the last 10 minutes of the task the LSMean in the Left eye became 0.549 (SEM = 0.014) across the 4 days and 0.507 (SEM = 0.013) for the Right eye. This equates to a 5% increase in both eyes.

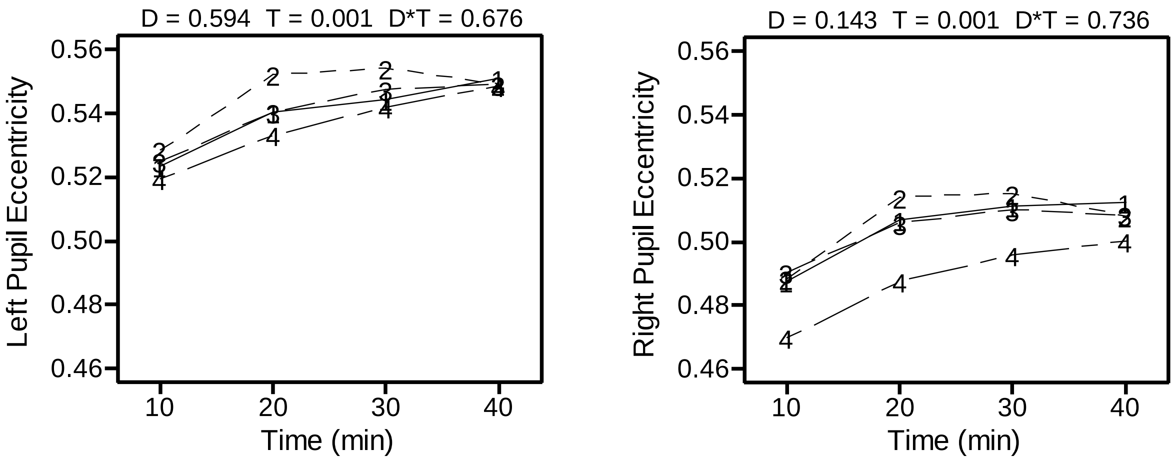

Figure 9. Left and Right Eye Pupil Eccentricity Across Time, by Day

Time on task also had a significant effect on Left and Right Pupil Velocity (Figure 10). Left Pupil Velocity during the first 10 minutes of the task had an LSMean of 0.268 degrees per second (SEM = 0.019) across the 4 days and an LSMean of 0.257 degrees per second (SEM = 0.019) in the Right eye. The LSMean for the last 10 minutes of the task in the Left eye was 0.351 degrees per second (SEM = 0.019) and 0.340 degrees per second (SEM = 0.019) for the Right eye. This equates to a 31% increase in saccadic velocity in the Left eye and a 33% increase in the Right eye.

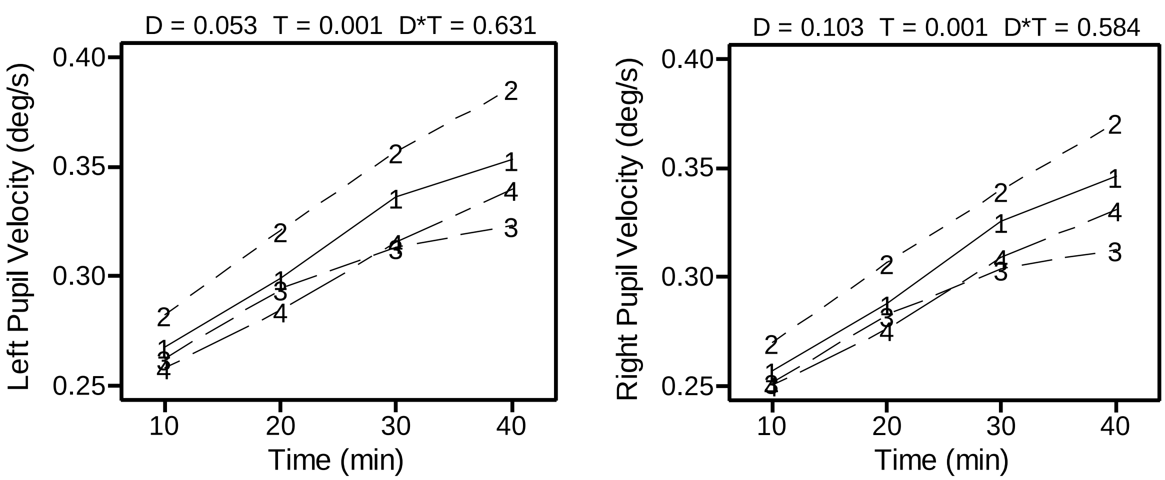

Figure 10. Left and Right Eye Pupil Velocity Across Time, by Day

An interaction effect for Day and Time was found for Right Blink Frequency, Right Blink Duration, and Right Pupil Diameter.

4.1.2 Correlations.

Pearson partial correlations controlling for subject were performed (separately for Decrement and No Decrement days) to relate Percent Hits to the eye metric variables. Table 2 displays the correlations with their corresponding p-value. Significant partial correlations have their cells grayed. Percent Hits was combined for both tasks to come up with a total percent hits score. If there was a decrease in performance in either task or both tasks that day was considered a decrement day.

Table 2. Pearson Partial Correlations Controlling for Subject

	Percent Hits			
	Decrement		No Decrement	
Variable Correlated With	r	p	r	p
Left Blink Frequency (blpm)	-0.29	0.0329	0.20	0.1622
Right Blink Frequency (blpm)	-0.20	0.1337	0.28	0.0412
Left Blink Duration (ms)	-0.43	0.0011	0.12	0.4095
Right Blink Duration (ms)	-0.36	0.0064	0.23	0.1026
Left PERCLOS	-0.40	0.0023	-0.07	0.6216
Right PERCLOS	-0.41	0.0021	0.06	0.6482
Left Pupil Diameter (mm)	0.53	0.0001	-0.07	0.6220
Right Pupil Diameter (mm)	0.55	0.0001	-0.14	0.3136
Left Pupil Eccentricity	-0.50	0.0001	0.11	0.4579
Right Pupil Eccentricity	-0.45	0.0005	0.09	0.5128
Left Pupil Velocity (deg/s)	-0.38	0.0037	0.33	0.0186
Right Pupil Velocity (deg/s)	-0.39	0.0033	0.33	0.0175

Left Blink Frequency (Figure 11), Left and Right Blink Duration (Figure 12), Left and Right PERCLOS (Figure 3), Left and Right Pupil Eccentricity (Figure 14) significantly correlated with Percent Hits in the Decrement group while Right Blink Frequency significantly correlated with Percent Hits in the No Decrement group. As performance decreases in the Decrement group, Left Blink Frequency, Left and Right Blink Duration, and Left and Right PERCLOS increased. There was no significant relationship found for Blink Duration, PERCLOS, Left and Right Pupil Eccentricity, in the No Decrement group.

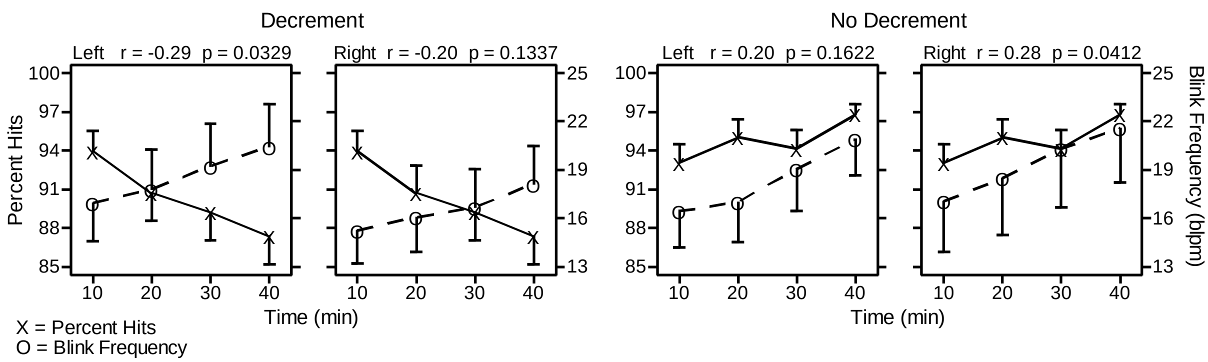

Figure 11. Mean Percent Hits and Left and Right Eye Blink Frequency Across Time, by Day

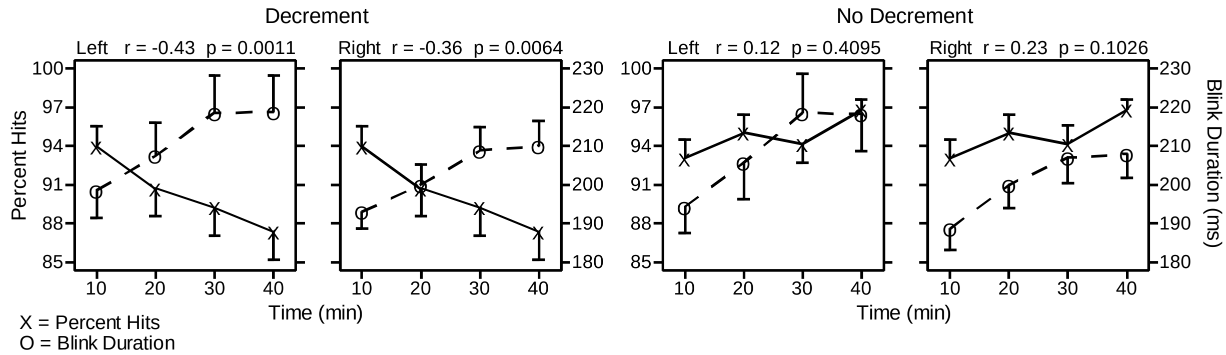

Figure 12. Mean Percent Hits and Left and Right Eye Blink Duration Across Time, by Day

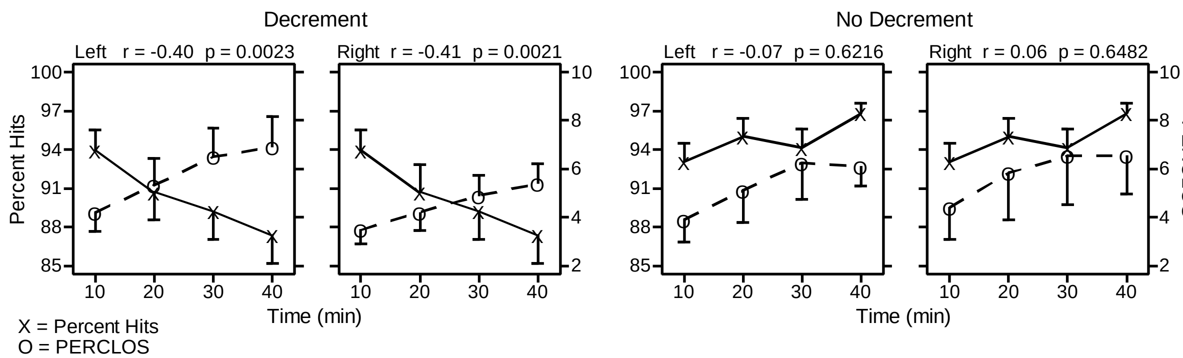

Figure 13. Mean Percent Hits and Left and Right Eye PERCLOS Across Time, by Day

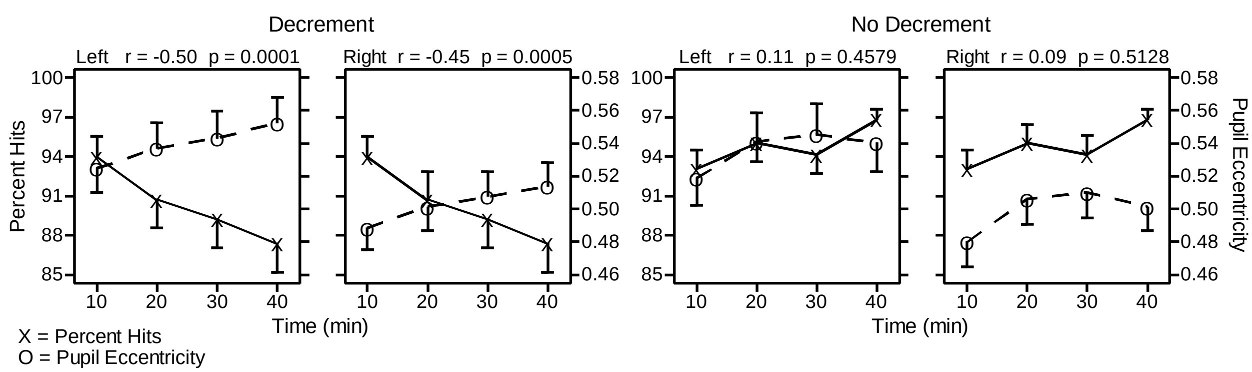

Figure 14. Mean Percent Hits and Left and Right Eye Pupil Eccentricity Across Time, by Day

Additionally, Left and Right Pupil Diameter were significantly correlated with Percent Hits in the Decrement group (Figure 15). As performance decreased on the task, Pupil Diameter decreased.

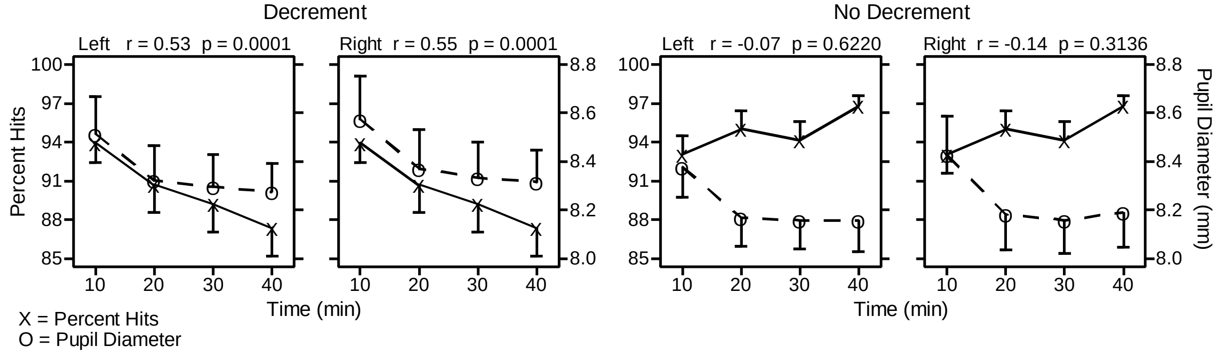

Figure 15. Mean Percent Hits and Left and Right Eye Pupil Diameter Across Time, by Day

Left and Right Pupil Velocity significantly correlated with Percent Hits in both the Decrement and No Decrement group (Figure 16). In the Decrement group, Pupil Velocity increases as performance decreases. In the No Decrement group, performance remains fairly stable across time. Pupil Velocity of the participants in this group increases at first before leveling off.

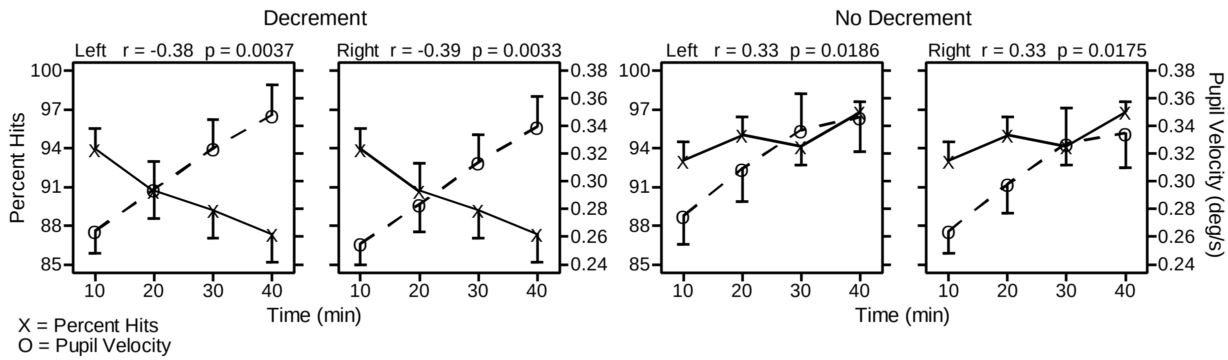

Figure 16. Mean Percent Hits and Left and Right Eye Pupil Velocity Across Time, by Day

For our demographic data results (Table 3), we found that the age of the participant had a strong correlation with vigilance performance. Essentially, younger persons were more likely to experience the vigilance decrement on any given day relative to older persons (ages ranged from 19 to 41 years with an average age of 27 years, n=36).

Table 3. Personality and Demographics (asterisk denotes statistical significance at an alpha level of .05; double asterisks denote significance at an alpha level of .01)

Measure	Age	Gender	Early Bird / Night Owl
Pearson's *r*	-.35	0.32	0.403
p-value (two tailed)	.036*	.054	.022**
Sample size	36	36	32

We also collected demographic data in which participants self-classified into “Night Owl” types (people who prefer to stay up late and sleep in) versus “Early Birds” (people who prefer to go to bed early and awaken early). We found a very strong relationship between self-classification of Early Birds/Night Owls and the propensity to incur a vigilance decrement on the days of testing. Specifically, we found a significant positive correlation ($r = .403$, p[two-tailed] = .022) suggesting that Night Owls are much more likely to demonstrate the vigilance decrement than Early Birds.

4.2 Discussion

The discussion section is broken into two separate parts, first the discussion on the eye metrics followed by the demographics discussion.

4.2.1 Oculometrics.

Our results suggest that the six oculometrics examined in our study correlated with changes in performance and should be considered in applications to monitor cyber operator vigilance. These include blink frequency, blink duration, PERCLOS, pupil diameter, pupil eccentricity, and pupil velocity. These metrics could be beneficial in reducing errors and improving cyber operator performance.

The results for blink frequency, blink duration, and PERCLOS showed that as attention decreased (performance declined) there was an increase in these oculometrics. This indicates that poor attention to a task could be measured by an increase in blink rate, longer blink durations, and a longer amount of time spent with the eyes closed. We found this same effect in a previous study using a less complex task (McIntire et al., 2011). The correlations were stronger for the previous study in all eye metrics but we believe this is just a reflection of increased variance moving away from a strictly controlled laboratory task to a more real-world relevant task with more potential sources of variance (McIntire et al., 2011). It is interesting to note that results for this current study indicate that Right Blink Frequency was the only metric to not significantly interact with Percent Hits for the Decrement group but it did for the No Decrement group. In the previous study, our results indicated that performance had a significant effect on blink frequency in the right eye only for the decrement group (McIntire et al., 2011). While no definitive explanation can be offered and because people do not typically blink their eyes independently of one another, we should note our observation that participants would completely close one eye and attempt to do the task with just one eye open as the task progressed probably as a countermeasure to fight task-induced fatigue. We should also note that in the decrement group, both eye blink frequency measures were negatively correlated with performance (although only the left eye correlation was statistically significant). The opposite pattern occurred in the no decrement group, in which both eye blink frequency measures were positively correlated with performance (again, only one eye’s correlation was significant). These results are suggestive of potentially low statistical power or small effect sizes, which may have been hampered by missing data and by splitting our overall results into two separate analyses (the decrement versus no decrement groupings). Whatever the explanation for these asymmetrical findings across the eyes, more research would be necessary into this particular eye metric before it could be recommended for implementation into a monitoring system.

Others have examined blink frequency and duration during a vigilance task and have consistently found an increase in these metrics as a function of time-on-task (Carpenter, 1984; Funke, 2011; Morris & Miller, 1996; Schroder & Holland, 1968). Similarly, Brookings, Wilson and Swain (1996) found that when participants were paying attention and concentrating on a hard high-workload task their blink rates would decline but when workload levels decreased their blink rates increased. This evidence leads us to believe this metric is still of possible use with more research on more operationally relevant tasks and environments.

On the other hand, PERCLOS appears to be one of the best metrics available for monitoring vigilance according to this study and our previous study (McIntire et al., 2011). Specifically, PERCLOS negatively correlated with performance and appears to mimic the fluctuations in performance for the Decrement group. Other research also indicates that PERCLOS is a useful indicator of performance declines induced by time-on-task fatigue (Dinges & Grace, 1998). Furthermore, studies have also shown that PERCLOS will change in response to changes in cognitive workload (Kawashima, O'Sullivan, & Roland, 1995; Marshall, 2007).

The one oculometric that positively correlated with performance was pupil diameter. Pupil diameter decreased as the number of critical signals detected also decreased. When pupil diameter is small the pupils are said to be miotic. Miosis occurred in our previous study as well as other studies on attention (Lowenstein, Feinberg, & Lowenfeld, 1963; Ludtke, et al., 1998; McIntire et al., 2011). These studies indicate that during miosis a participant's performance is at its worst (Nishiyama et al., 2007; Tsai et al., 2007). Therefore, several previous studies that also found a decrease in pupil diameter suggest that pupil diameter may be an indicator of poor attention (Nishiyama et al., 2007; Warga et al., 2009), which is consistent with our findings from both studies.

As performance on the task decreased an increasing pupil velocity was found. Because our pupil velocity never surpassed 3 degrees per second our observations were classified as microsaccades, as opposed to the larger and more familiar saccades. This is consistent with findings from our previous study (McIntire et al., 2011). We believe our observations are unlikely to be full saccades because the viewing window for the critical signals is so small that full saccades are not necessary to perform well on the task. Saccadic velocity does appear to be related to attention not only through our research but by others as well. Galley (1989) found that tasks requiring high levels of vigilance increased participant's saccadic velocity. In fact, the oculomotor readiness hypothesis states that the movement that controls attention, fixation, and saccades belongs to the same neural circuitry (Rizzolatti, Riggio, Dascola & Umiltá, 1987); therefore, attending to a certain location should result in faster saccades (Hoffman & Subramaniam, 1995). Our results of increasing microsaccades with time-on-task could be indicating that the participant is trying to attend to the task more because they are aware of their decreasing arousal levels. It is important to note that pupil velocity significantly interacted with the No Decrement group as well (although the correlations were in opposite directions across groups). More research is needed into this metric to determine exactly what information it is conveying about behavior.

Pupil eccentricity was found to increase as the number of critical signals detected decreased for the Decrement group. This finding is also concordant with our previous study (McIntire et al., 2011). Pupil eccentricity is increasingly occurring because as closure of the eyes as indicated by blink duration, blink frequency, and PERCLOS increases with time-on-task, the pupils become more occluded by the eyelids causing their shapes to appear more elliptical than round to the eye image analysis software that calculates their shape (Liu, Sun, & Shen, 2010). Furthermore, Lowenstein and Loewenfeld (1962) believe that pupil eccentricity is an indicator of arousal levels. In general, pupillary activity is used in fatigue research as an indicator of arousal levels because pupillary activity is considered the most observable indicator of autonomic nervous system activation (Goldich, Barkana, Pras, Zadok, Hartstein, & Morad, 2010). Therefore, our findings on pupillary activity (pupil diameter, pupil eccentricity, and pupil velocity) coupled with findings from previous research lead us to believe that a good system to monitor sustained attention should include monitoring pupillary activity.

As expected for our experiment, the factor of Time was significant for all oculometrics. As time-on-task progressed blink frequency increased 25%, blink duration increased 38%, PERCLOS increased 58%, pupil diameter decreased 3%, pupil eccentricity increased 5%, and pupil velocity increased 32% for all subjects and sessions (i.e. not broken out into specific groups). These changes indicate that the eyes may reflect the changing attention levels throughout the task. The factor of Day also had a significant effect on

Percent Hits for the graphical portion of the task. Percent Hits increased as the participation day progressed (Figure 3). In other words, participants got slightly better at detecting the critical signals for this portion of the task with each new day of participation. This is likely to be a training or practice effect that is commonly observed in repeated measures experiments.

4.2.2 Demographics.

For our demographic data results, we found that the age of the participant had a strong correlation with vigilance performance. Essentially, younger persons were more likely to experience the vigilance decrement on any given day relative to older persons. Although previous research has also claimed a relationship between gender and fatigue, specifically with men being more resilient to the effects of fatigue (DeVries & Van Heck, 2002), thus suggesting a possible similar relationship with vigilance, we found no compelling evidence either way although the trend favored women. Admittedly, this finding is just fractionally non-significant potentially due to our sample size being rather small and skewed to over-representation of males with about 20% female volunteers; or 7 female participants in our current combined sample size of 36, so this trend might well disappear with further research.

We also collected some demographic data in which participants self-classified into “Night Owl” types (people who prefer to stay up late and sleep in) versus “Early Birds” (people who prefer to go to bed early and awaken early). We found a very strong relationship between self-classification of Early Birds/Night Owls and the propensity to incur a vigilance decrement on the days of testing. Specifically, we found that Night Owls are much more likely to demonstrate the vigilance decrement than Early Birds. All participants’ data collection was done during normal business hours, many of which occurred in the morning hours, which could suggest that Night Owls might not have been fully awake (perhaps near a low point in their circadian cycle). Future research on this topic might find it useful to record time of day of each session, the number of hours of sleep the few days before, sleeping and rising times, subjective ratings of sleep quality, etc. It might also be interesting to investigate the extent to which self-classified “Early Birds” are actually able to go to bed late and sleep-in versus their actual sleep times.

5.0 CONCLUSION

Our results indicate that changes in oculometrics correspond to changes in vigilance performance during a cyber operator task. These results are reflective of previous findings using a potentially less operationally relevant task (McIntire et al., 2011). Therefore, it appears that moving toward a more operationally relevant task is possible and that field testing is necessary and possible using this method. Implementation of an eye-tracking device to monitor the attention of cyber operators may significantly decrease human error in the future and possibly avoid devastating consequences of vigilance lapses through the use of alerting perceptual cues or non-invasive brain stimulation techniques to augment human performance. Future research is needed to assess these oculometrics in real-time and to assess their effectiveness in the field. Also, the wearable eye-tracker used in this study proved to lend itself well to a more operational environment compared to off-body trackers although the most useful tracker in an operational setting would need to be wireless.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analyses of Variance
CDT	Cyber Defense Task
LED	Light Emitting diode
IP	Internet Protcol
IR	Infared
LSMeans	Least Squares Means
PERCOS	Percentage of Eye Closure
SAS	Statistical Analysis Software
SEM	Standard Error of the Mean
UDDI	University of Dayton Research